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DISPERSION CHEMICAL REACTION AND RADIATION EFFECTS ON HEAT AND MASSTRANSFER IN MIXED CONVECTIVE FLOW CONSIDERING SORET AND DUFOUR EFFECTS

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ABSTRACT

In the present study we investigate the effects of mixed convection along a vertical plate in a non-Darcy Newtonian fluid saturated porous medium in the presence of chemical reaction, radiation, double dispersion, Soret and Dufour effects for different fluid flows. Introducing the similarity variables to transform the system of partial differential equations in the coupled non-linear differential equations. The non-linear differential equations are solved by using Runge-Kutta 4^{th} order method coupled with the double shooting technique. The effects of velocity, temperature, concentration, Heat and mass transfer rates for different parameters are calculated.

Key words: *Heat and Mass transfer, Mixed Convection, Soret effect, Dufour effect.*

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1. NOMENCLATURE:

c	Empirical constant
C	Concentration
c_p	Specific heat at constant pressure
d	Pore diameter
D	Mass diffusivity
f	Dimensionless stream function
$F_0 Pe$	Representing non-Darcian effect
g	Gravitational acceleration
k	Molecular thermal conductivity
K	Permeability of the porous medium
K_1	Dimensionless Chemical reaction parameter
k_d	Dispersion thermal conductivity
k_e	Effective thermal conductivity
Le	Lewis number
n	Order of reaction
N	Buoyancy ratio
Nu_x	Local Nusselt number

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p	Pressure
$\Pr$	Prandtl number
q	Heat transfer rate
Ra	Rayleigh number
Re_x	Local Reynolds number
Sc	Schmidt number
Sh_x	Local Sherwood number
T	Temperature
u, v	Velocity components in the x and y directions
$\mathbf{v}$	Velocity vector
x, y	Axes along and normal to the plate
α	Molecular thermal diffusivity
α_d	Dispersion diffusivity
α_x, α_y	Components of the thermal diffusivity in x and y directions
β_T	Thermal expansion coefficient
β_C	Solutal expansion coefficient
R	Radiation parameter
γ_1	Non-dimensional chemical reaction parameter
ϕ	Dimensionless concentration
γ	Mechanical thermal-dispersion coefficient
η	Similarity space variable
μ	Fluid dynamic viscosity
υ	Fluid kinematic viscosity
θ	Dimensionless temperature
ρ	Fluid density
ψ	Stream function
ζ	Mechanical solutal-dispersion coefficient
σ	Electrical conductivity, mho
σ_0	Stefan-Boltzmann constant
k_1^*	Mean absorption coefficient
$\frac{Ra}{Pe}$	Mixed convection parameter

SUBSCRIPTS:

d	Pore diameter
x, y	In the directions of x and y axes
w	Surface conditions
∞	Conditions away from the surface

SUPERSCRIPTS:

'	Derivative with respect to η

2. INTRODUCTION:

Mixed convection flow over a vertical surface embedded in a saturated porous medium has many engineering applications such as Nuclear reactors. Transport processes in porous media play a significant role in various applications, such as geothermal engineering, thermal insulation, energy conservation, petroleum industries, solid matrix heat exchangers, chemical catalytic reactors, and underground disposal of nuclear waste materials. Chemical reaction effects should be considered in many applications of heat and mass transfer especially those encountered in chemical reactors of porous structure, geothermal reservoirs, radiation heat transfer accounts in high temperature applications viz., plasma physics, nuclear reactions, liquid metal flows, magneto hydrodynamic accelerators and in power generation systems. Cheng and Minkowycz [1] presented similarity solutions for free convective heat and mass transfer from a vertical plate in a fluid saturated porous medium. Anjalidevi and Kandasamy [2] investigated the effects of chemical reaction and heat and mass transfer on a laminar flow along a semi-infinite horizontal plate. Flow and mass transfer on a stretching sheet with a magnetic field and chemically reactive species have been investigated by Takhar et al. [3] Alam et al. [4] investigated the effects of first order chemical reaction and thermophoresis on MHD mixed convective heat and mass transfer flow along an inclined plate in the presence of heat generation/absorption with viscous dissipation and joule heating. Anwar B'eg et al. [5] studied numerically free convection magneto hydrodynamic heat and mass transfer from a stretching surface to a saturated porous medium with Soret and Dufour effects. Partha et al. [6] looked for the effect of double dispersion, Dufour and Soret effects in free convection heat and mass transfer in a non-Darcy electrically conducting fluid saturating porous medium. Lakshmi Narayana and Murthy [7] studied the Soret and Dufour effects in a doubly stratified Darcy porous medium. Later on, Lakshmi Narayana and Murthy [8] analyzed Soret and Dufour effects on free convection heat and mass transfer from a horizontal flat plate in a Darcy porous medium, and obtained similarity solutions in the case of constant wall temperature and concentration. Mixed convection in the presence of Soret and Dufour effects was tackled by Chamkha and Ben-Nakhi [9]. Additional effects included in that paper were MHD, radiation and permeability of the plate (placed in a porous medium). This time, the set of governing equation is no more reduced to ordinary differential equations, but to partial ones, of parabolic type, through appropriate transformation of variables. Murthy [10] analyzed the effect of double dispersion on mixed-convection heat and mass transfer in a non-Darcy porous medium. . The present work is to illustrate the effects of double dispersion on mixed convection heat and mass transfer in non-Darcy, Newtonian fluid with chemical reaction, Radiation, Soret and Dufour effects along a vertical plate.

3. MATHEMATICAL FORMULATION:

Consider the study of two dimensional non-Darcy Mixed convection flow, heat and mass transfer over a vertical surface in a fluid-saturated porous medium.

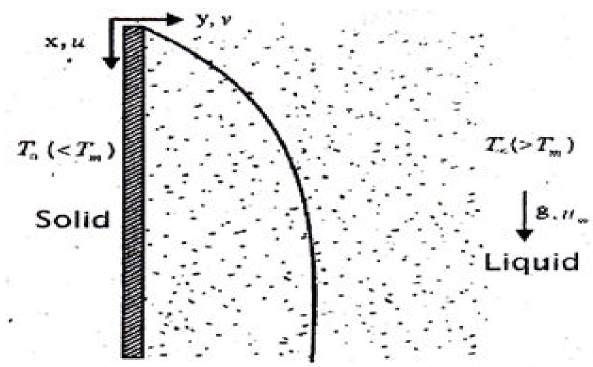

Fig.1

Figure 1 shows a schematic drawing of the problem in which the x-direction points upward along the wall and the y-direction is normal to the wall. The wall is maintained at constant temperature T_w and concentration C_w. We have added Radiation and chemical reaction terms to the energy and concentration equations. Under these assumptions the governing equations can be written as follows.

Equation of Continuity:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

Equation of Momentum:

$$\frac{\partial u}{\partial y}+\frac{c\sqrt{K}}{\upsilon}\frac{\partial u^2}{\partial y}=\frac{Kg\beta_T}{\upsilon}\frac{\partial T}{\partial y}+\frac{Kg\beta_C}{\upsilon}\frac{\partial C}{\partial y} \tag{2}$$

Equation of Energy:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_m\frac{\partial^2 T}{\partial y^2}+\frac{D_m}{Cs}\frac{K_T}{C_\rho}\frac{\partial^2 C}{\partial y^2}-\frac{1}{\rho c_p}\frac{\partial q}{\partial y} \tag{3}$$

where $\frac{\partial q}{\partial y} = -16 a\sigma R T_\infty^3 \left(T_\infty - T\right)$

Equation of Concentration:

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_m \frac{\partial^2 C}{\partial y^2} + \frac{D_m K_T}{T_m}\frac{\partial^2 T}{\partial y^2} - K_1 C^n \quad (4)$$

Equation of state $\rho = \rho_\infty \left[1 - \beta_C \left(T - T_\infty\right) - \beta_T \left(C - C_\infty\right)\right]$ (5)

The boundary conditions are

$$\left.\begin{array}{l} y = 0\ ;\ v = 0,\ T = T_w, C = C_w \\ y \to \infty ; u = 0, T = T_\infty, C = C_\infty \end{array}\right\}. \quad (6)$$

where u and v are velocities in the x and y directions respectively, υ is a kinematic viscosity, g is the acceleration due to gravity, β_c and β_T are the coefficients of thermal and solute dispersion expansions, T is the temperature of the fluid in the thermal boundary layer, T_w is the wall temperature, T_∞ is the free stream temperature far away from the plate. C is the Species concentration of the boundary layer, C_w is concentration of the plate , C_∞ is the free stream temperature far away from the plate. K is the permeability the constant. ρ is the density of the fluid. D_m is the molecular diffusivity of the spices of concentration, T_m is the mean fluid temperature, K_T is the thermal diffusivity ratio, K_1 is the chemical reaction and $\left(n = 1\right)$ is the order of the reaction. The energy equation includes radiation heat transfer effect with Jowl heating. The radiative heat flux term q is written by using the Rosseland approximation as $q = -\frac{4\sigma_0}{3k_1^*}\frac{\partial T^4}{\partial y}$, where σ_0, k_1^* Stefan-Boltzmann constant and the mean absorption coefficient respectively.The chemical reaction term is added as the last-term in the right hand side of equation (4). It is assumed that the normal component of the velocity near the boundary is small compared with the other components of the velocity and the derivatives of any quantity in the normal direction are large compared with derivatives of the quantity. Expanding T^4 about T_e by using Taylor's series and neglecting higher order terms we get $T^4 \cong 4T_e^3 T - 3T_e^4$.

Introducing the stream function ψ such that $u = \frac{\partial \psi}{\partial y}$ and $v = -\frac{\partial \psi}{\partial x}$

and similarity variables as $\psi = f\left(\eta\right)\left(\alpha_m u_\infty x\right)^{\frac{1}{2}}$, $\eta = \left(\frac{u_\infty x}{\alpha_m}\right)^{\frac{1}{2}}\left(\frac{y}{x}\right)$, $\theta\left(\eta\right) = \frac{T - T_\infty}{T_w - T_\infty}$

$\phi\left(\eta\right) = \frac{C - C_\infty}{C_w - C_\infty}$

the momentum (2), energy(3) and concentration (4) equations are reduced to

$$f'' + 2F_0 Pe\, f' f'' = \frac{Ra}{Pe}\left(\theta' + N\phi'\right) \quad (10)$$

$$\theta'' + \frac{1}{2} f\theta' + D_f \phi'' + Pe_\gamma\left(f'\theta'' + f''\theta'\right) + \frac{4R}{3}\left[3\theta'\left(\theta + c_r\right)^2 + \theta''\left(\theta + c_r\right)^3\right] = 0 \quad (11)$$

$$\phi'' + \frac{1}{2} Le f \phi' + Le S_r \theta'' + Le Pe_\xi\left(f'\phi'' + f''\phi'\right) - \frac{Ra}{Pe} Le\, \gamma_1 \phi^n = 0 \quad (12)$$

where the prime denotes the differentiation with respect to the similarity variable η and $\frac{Ra_x}{Pe_x}$ is the mixed convection parameter, $Ra_x = \frac{Kg\beta_T (T_w - T_\infty) x}{\upsilon \alpha_m}$ is the local Rayleigh number, $Pe_x = \frac{u_\infty x}{\alpha_m}$ is the local Peclect number, $N = \frac{\beta_C (C_w - C_\infty)}{\beta_T (T_w - T_\infty)}$ is buoyancy ratio parameter. The inertial parameter $F_0 Pe = \frac{c\sqrt{K} u_\infty}{\upsilon}$, $Le = \frac{\alpha_m}{b}$ is the diffusivity ratio. $Pe_\gamma = \frac{\gamma d\, u_\infty}{\alpha_m}$ is the thermal dispersion and $Pe_\xi = \frac{\xi d u_\infty}{\alpha_m}$ is the solutal dispersion parameter respectively. $R = \frac{4\sigma\theta_w^2}{kk_1^*}$ is the conduction radiation parameter, $D_f = \frac{D_m k_T (C_w - C_\infty)}{C_s C_\rho \alpha_m (T_w - T_\infty)}$ is Dufour effect, $S_r = \frac{D_m k_T (C_w - C_\infty)}{T_m \alpha_m (T_w - T_\infty)}$ is the Soret effect. The constant dimensionless chemical reaction parameter is $\gamma_1 = \frac{K_1}{\alpha_m} . \frac{x^2}{Ra_x}$. The transformed boundary conditions are

$$f(0) = 0, \theta(0) = \phi(0) = 1 \,,\, f'(\infty) = 1, \theta(\infty) = \phi(\infty) = 0 \tag{13}$$

Now the heat transfer, mass transfer coefficients can be written in terms of local nusselt number and Sherwood number as

$$\frac{Nu_x}{(Ra_x)^{\frac{1}{2}}} = -\left[1 + Pe_\gamma f'(0)\right]\theta'(0) \,,\; \frac{Sh_x}{(Ra_x)^{\frac{1}{2}}} = -\left[1 + Pe_\xi f'(0)\right]\phi'(0)$$

4. SOLUTION PROCEDURE

The coupled non-linear ordinary differential equations (10), (11) and (12) along with the boundary conditions (13) are solved numerically by the fourth order Runge-Kutta method with the double shooting technique. By giving appropriate hypothetical values for $f'(0)$, $\theta'(0)$ and $\phi'(0)$ we get the corresponding boundary conditions for $f'(\infty)$, $\theta(\infty)$, $\phi(\infty)$ respectively. In addition, the boundary condition $\eta \to \infty$ is approximated by $\eta_{\max} = 4$ which is found to be sufficiently large for the velocity and temperature to approach the relevant free stream properties. This choice of $\eta_{\max}$ helps in comparison of our results with those of earlier works.

5. RESULT AND DISCUSSION:

In this analysis we have discussed the Soret and Dufour effects, double dispersion on heat and mass transfer in non-Darcy free convective flow over a vertical surface. The velocity, temperature, concentration, heat and mass transfer effects have been analyzed for different sets of parameters $F_0 Pe, S_r, D_f, Le, \gamma, \zeta, \gamma_1, R$ and presented in figures. The non-Darcian nature of the medium is reflected quantitatively in values we described to $F_0 Pe$. In fixing the parametric value ranges for $F_0 Pe, S_r, D_f, Le, \gamma, \zeta, \gamma_1, R$ quantitatively, we followed earlier works and carried out the computations. This helps in validating / computing the present results with relevant earlier published results. Extensive calculations have been performed to obtain the flow, temperature and concentration fields for a wide range of parameters: $0 \le F_0 Pe \le 1$, $0 \le Le \le 10$, $0 \le R \le 1$ and $n = 1$ for the two cases $N > 0$ and $N < 0$. In this problem we put $S_r = 0, D_f = 0, \gamma_1 = 0$ the results are matched with the results of Murthy [10].

It is found from the figure 2 that velocity decreases with an increase in inertia parameter for a fixed value of mixed convection parameter. For a fixed value of inertia parameter velocity decreases with decrease in mixed convection parameter.

The effect of temperature for different values of inertia and mixed convection are shown in Figure 3. It is clear from the figure that temperature decreases with an increase in mixed convection parameter for fixed value of inertia and the same trend is observed for the fixed values of inertia also.

From Figure 4. it observed that for a fixed value of mixed convection parameter velocity increases with an increase in Lewis number. This increment is less near the wall than far from the wall. For a fixed value of Lewis number velocity decreases with decrease in mixed convection parameter

It is observed from figure 5 that temperature decreases with an increase in mixed convection parameter for fixed values of Lewis number. It is also found that with an increase in Lewis number for a fixed value of mixed convection parameter temperature decreases.

From the figure 6 we observe that velocity increases with an increase in mixed convection parameter for a fixed value of chemical reaction parameter. For a fixed value of mixed convection parameter velocity increases with an increase in chemical reaction parameter. The increment is more with an increase in mixed convection parameter.

It is observed from the figure7 that temperature decreases with an increase in chemical reaction parameter for a fixed value of mixed convection parameter. It also shows that for a fixed value of chemical reaction temperature decreases with an increase in mixed convection parameter. For a fixed value of mixed convection parameter decrease in temperature is negligible.

Figure 8. Shows that the effect of velocity profile for different values of Soret effect, Dufour effect and mixed convection parameters. It is observed that velocity increases with an increase in mixed convection parameter for different values of Soret and Dufour effect. Velocity decreases with decrease in the values of Soret and Dufour effect for fixed values of the mixed convection parameter.

It is observed from the figure 9 that for the fixed values of Soret and Dufour effects. temperature decreases with an increase in mixed convection parameter.

From fig.10 we observe that Effect of chemical reaction on Nusselt number for different values of Lewis number and mixed convection parameters. It is clear that Nusselt number decreases with an increase in Lewis number for fixed values of mixed convection parameter. i.e., heat transfer coefficient decreases with decrease in Lewis number. It also shows that for a fixed value of Lewis number Nusselt number increase with an increase in mixed convection parameter. Figure 11. Shows that Sherwood number increases with an increase in mixed convection parameter for fixed values of Lewis number i.e., heat transfer coefficient increases with an increase in mixed convection parameter. It also shows that heat transfer coefficient increase with an increase in Lewis number for fixed values of mixed convection parameter.

It is clear from the figure 12 that Nusselt number increases with an increase in buoyancy ratio for fixed values of mixed convection parameter. It is also observed that with an increase in buoyancy ratio heat transfer rate increases more for a fixed value of mixed convection parameter. In the case of opposing buoyancy heat transfer rate increases but this increment is more in presence of aiding buoyancy than the opposing buoyancy.

From figure13. We observe that mass transfer coefficient increases with an increase in mixed convection parameter for a fixed value of buoyancy ratio. It is also observed that for a fixed value of mixed convection parameter Sherwood number increases with an increase in buoyancy ratio.

From Figure 14. It is observed that Nusselt number increases with an increase in mixed convection parameter for fixed values of thermal dispersion and solute dispersion. It is also observed that Nusselt number increases with an increase in solute dispersion, thermal dispersion and mixed convection parameters. It is also found that heat transfer coefficient increases with an increase in solute dispersion, thermal dispersion for a fixed value of mixed convection parameters.

It is observed from the figure 15 that Sherwood number increases with an increase in mixed convection parameter for fixed values of thermal dispersion and solute dispersion. For fixed values of mixed convection, Sherwood number increases with an increase in thermal and solute dispersions.

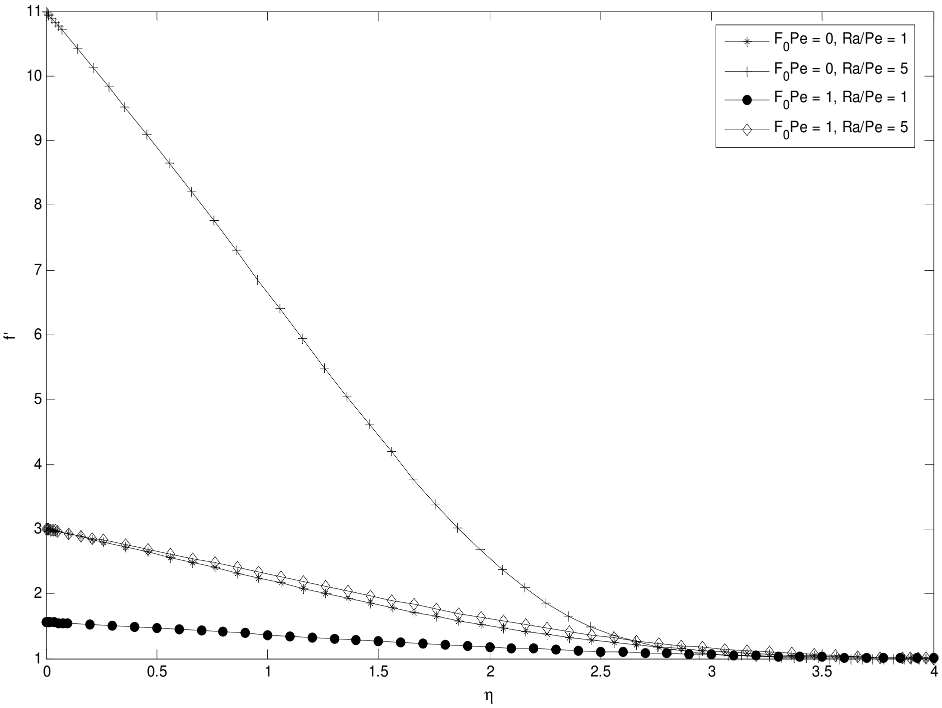

Fig. (2): Variation of $f^{'}(\eta)$ with η for different values of $F_0 Pe, \frac{Ra}{Pe}$

$$\left(N=1, Le=1, R=1, \gamma_1=0.2, S_r=0.1, D_f=0.6, Pe_\gamma=1, Pe_\xi=1\right)$$

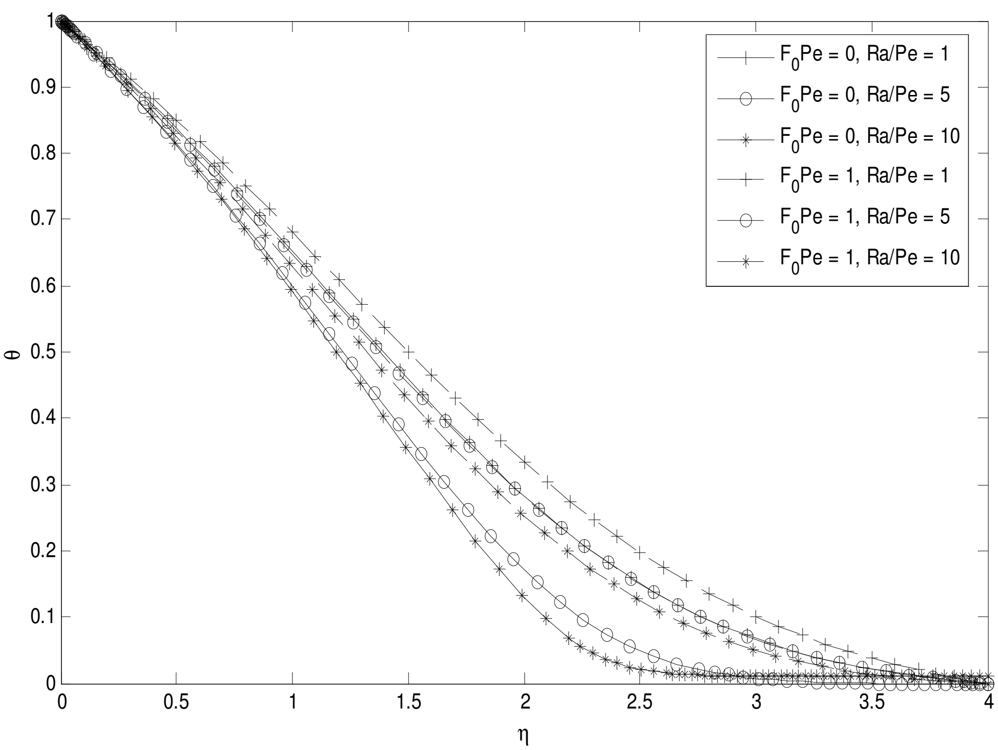

Fig. (3): Effects of Inertia and mixed convection on temperature for different values of $F_0 Pe, \frac{Ra}{Pe}$

$$\left(N=1, Le=1, R=1, \gamma_1=0.2, S_r=0.1, D_f=0.6, Pe_\gamma=1, Pe_\xi=1\right)$$

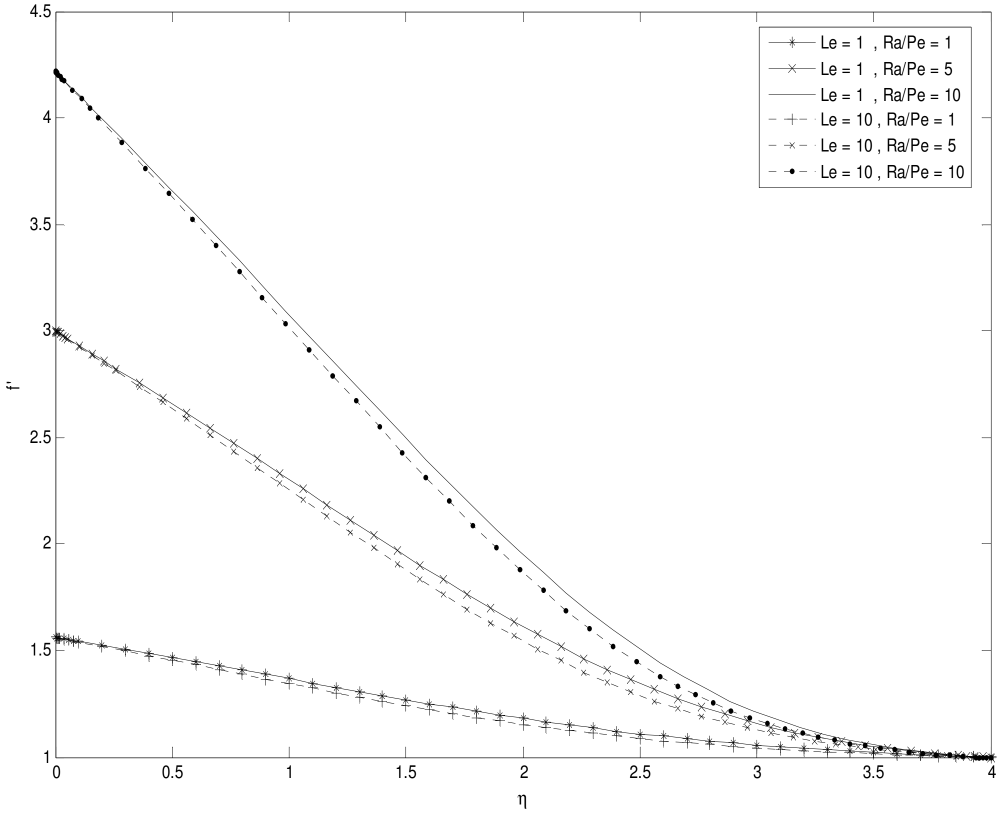

Fig. (4): Variation of $f^{'}(\eta)$ with η for different values of $Le, \dfrac{Ra}{Pe}$

$$\left(F_0Pe = 1, N = 1, R = 1, \gamma_1 = 0.2, S_r = 0.1, D_f = 0.6, Pe_\gamma = 1, Pe_\xi = 1\right)$$

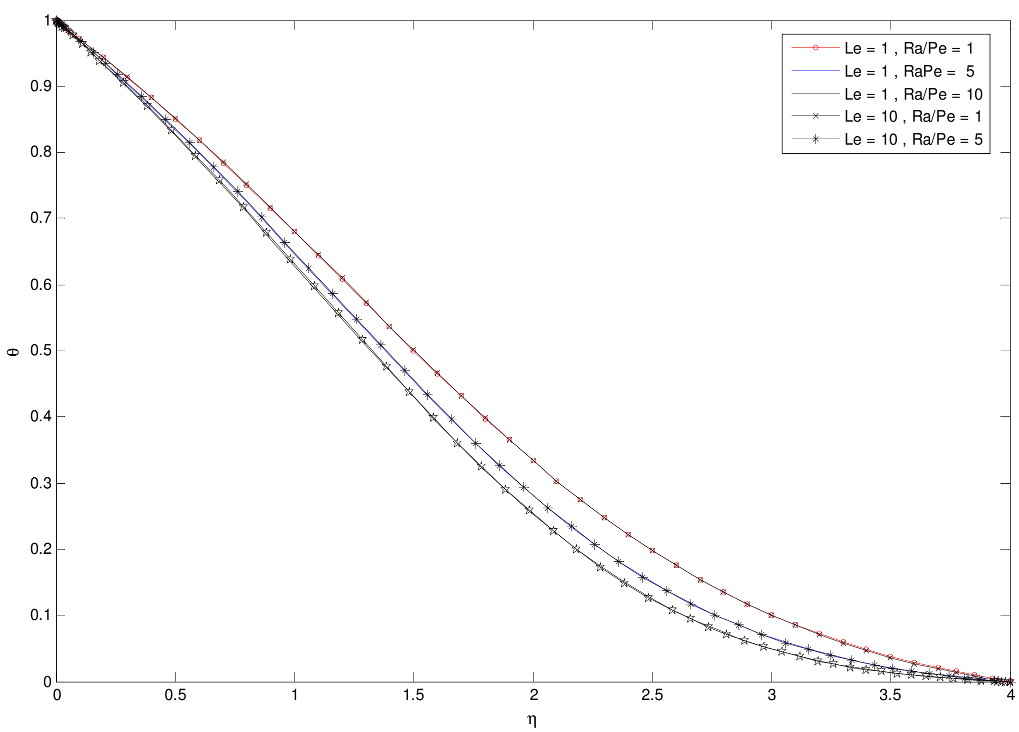

Fig. (5): Effects of Lewis number and mixed convection on temperature profile

$$\left(F_0Pe = 1, N = 1, R = 1, \gamma_1 = 0.2, S_r = 0.1, D_f = 0.6, Pe_\gamma = 1, Pe_\xi = 1\right)$$

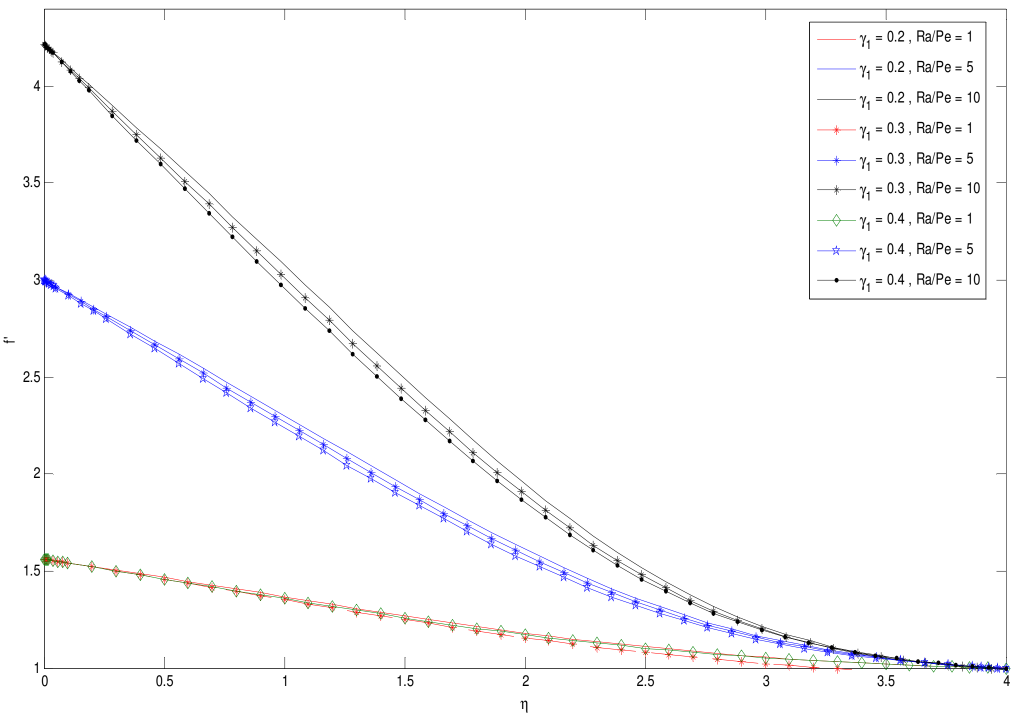

Fig. (6): Effects of Chemical reaction and mixed convection on velocity profile

$$\left(F_0Pe=1, N=1, Le=1, R=1, S_r=0.1, D_f=0.6, Pe_\gamma=1, Pe_\xi=1\right)$$

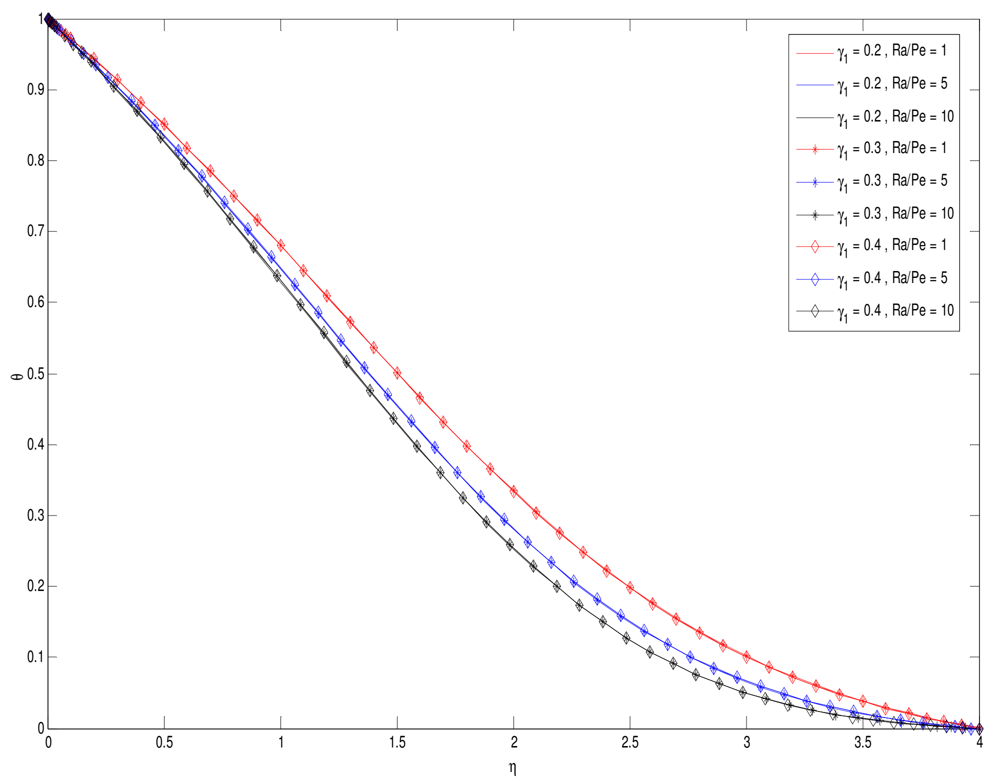

Fig. (7): Variation of Chemical reaction and mixed convection on temperature profile

$$\left(F_0Pe=1, N=1, Le=1, R=1, S_r=0.1, D_f=0.6, Pe_\gamma=1, Pe_\xi=1\right)$$

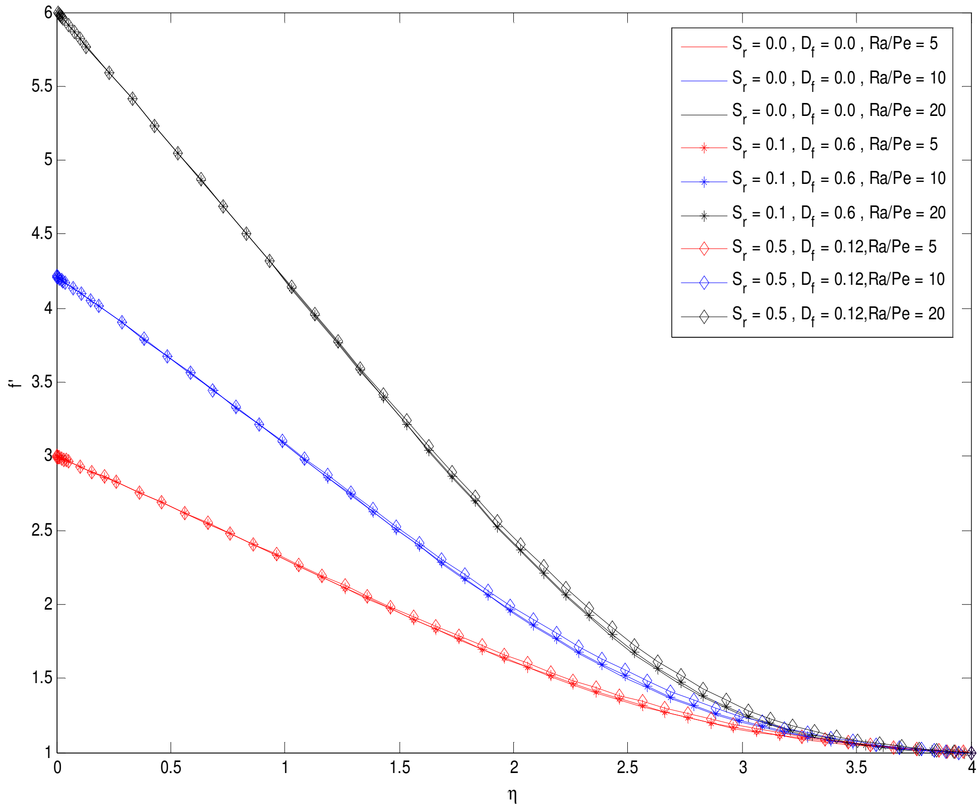

Fig. (8): Variation of Soret effect, Dufour effect and mixed convection on velocity profile

$$\left(F_0 Pe = 1, N = 1, Le = 1, R = 1, \gamma_1 = 0.2, Pe_\gamma = 1, Pe_\xi = 1\right)$$

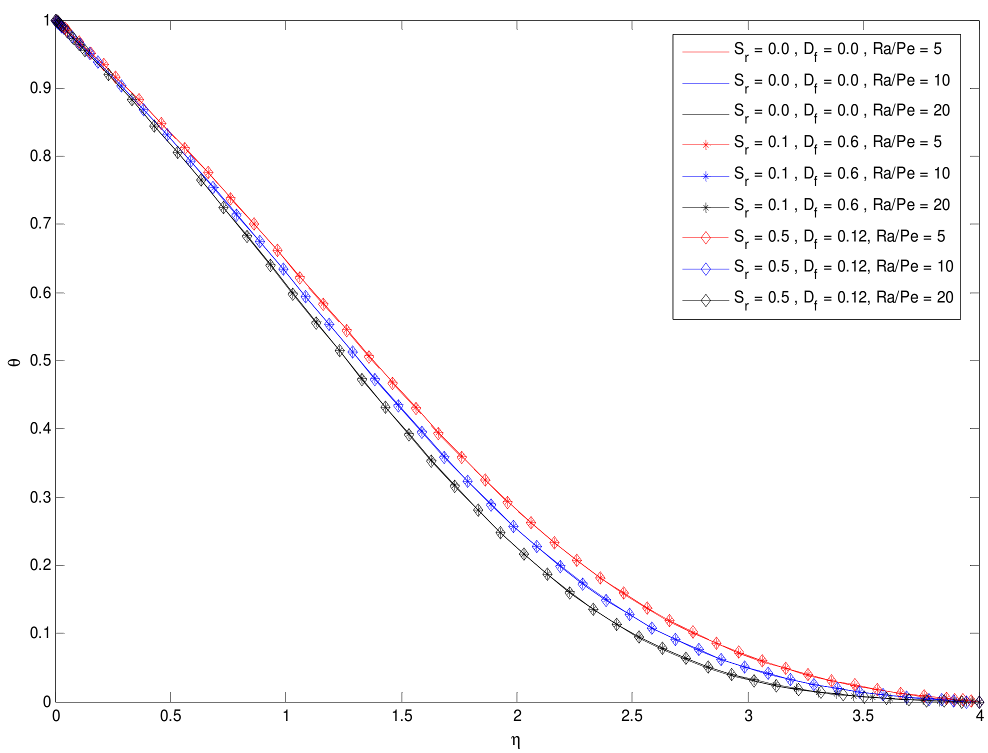

Fig. (9): Effects of Soret effect, Dufour effect and mixed convection on temperature profile

$$\left(F_0 Pe = 1, N = 1, Le = 1, R = 1, \gamma_1 = 0.2, Pe_\gamma = 1, Pe_\xi = 1\right)$$

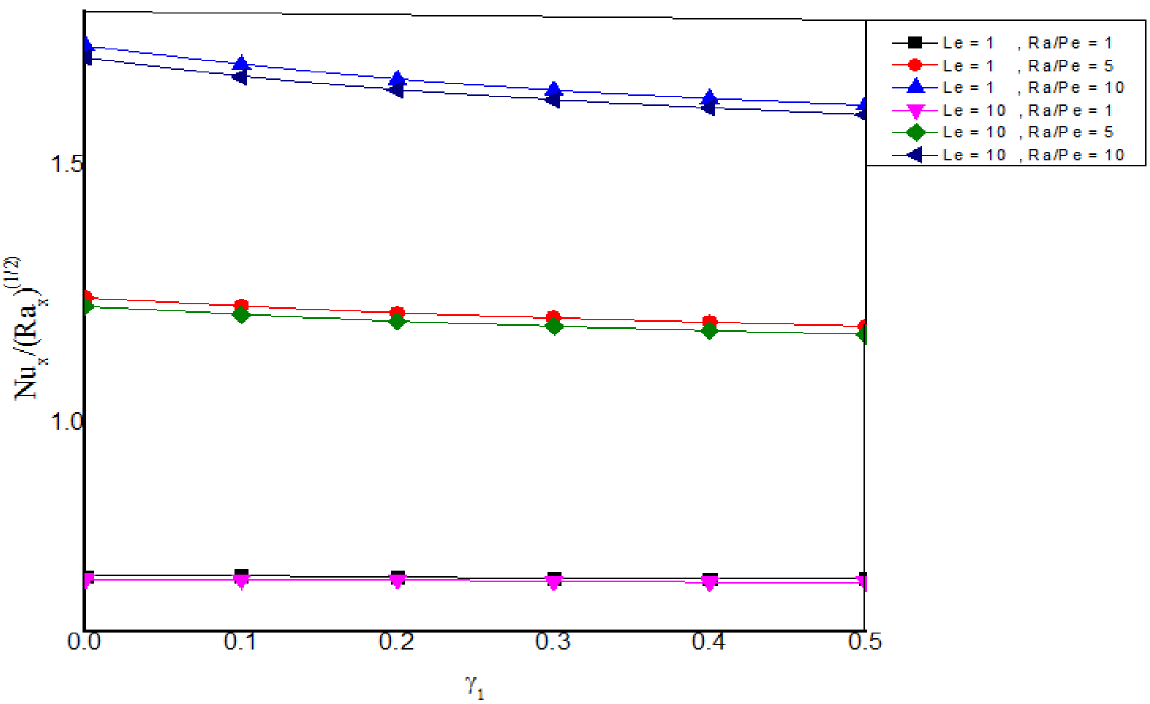

Fig. (10): Effects of chemical reaction parameter on Nusselt number for different values $Le, \dfrac{Ra}{Pe}$

$$\left(F_0 Pe = 1, N = 1, R = 1, S_r = 0.1, D_f = 0.6, Pe_\gamma = 1, Pe_\xi = 1\right)$$

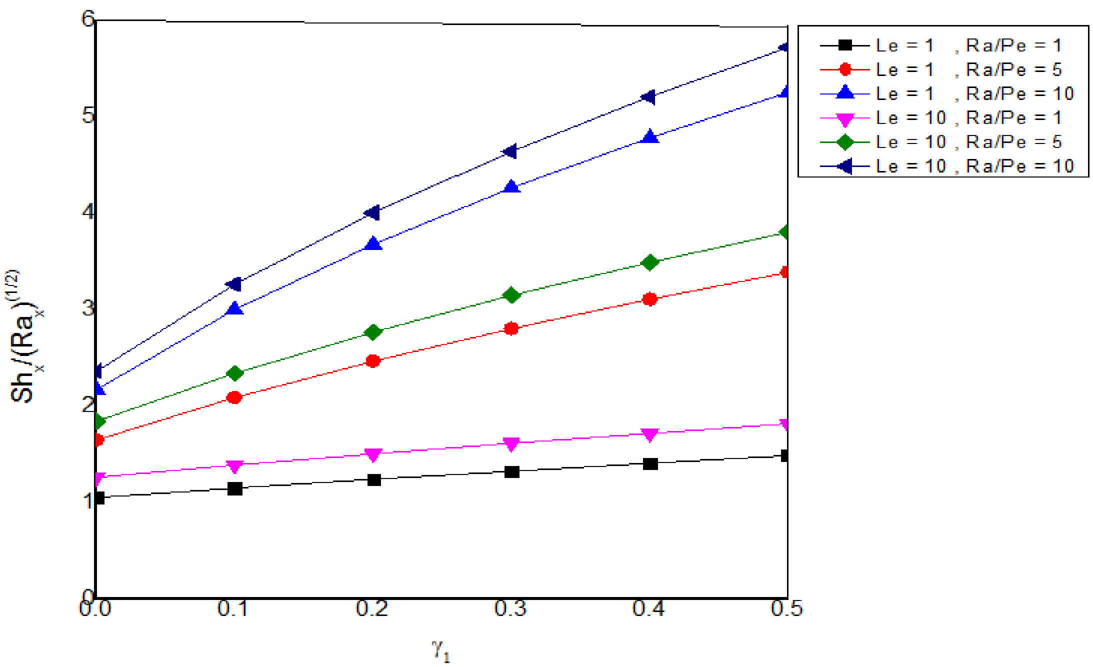

Fig. (11): Effects of chemical reaction parameter on Sherwood number for different values of $Le, \dfrac{Ra}{Pe}$

$$\left(F_0 Pe = 1, N = 1, R = 1, S_r = 0.1, D_f = 0.6, Pe_\gamma = 1, Pe_\xi = 1\right)$$

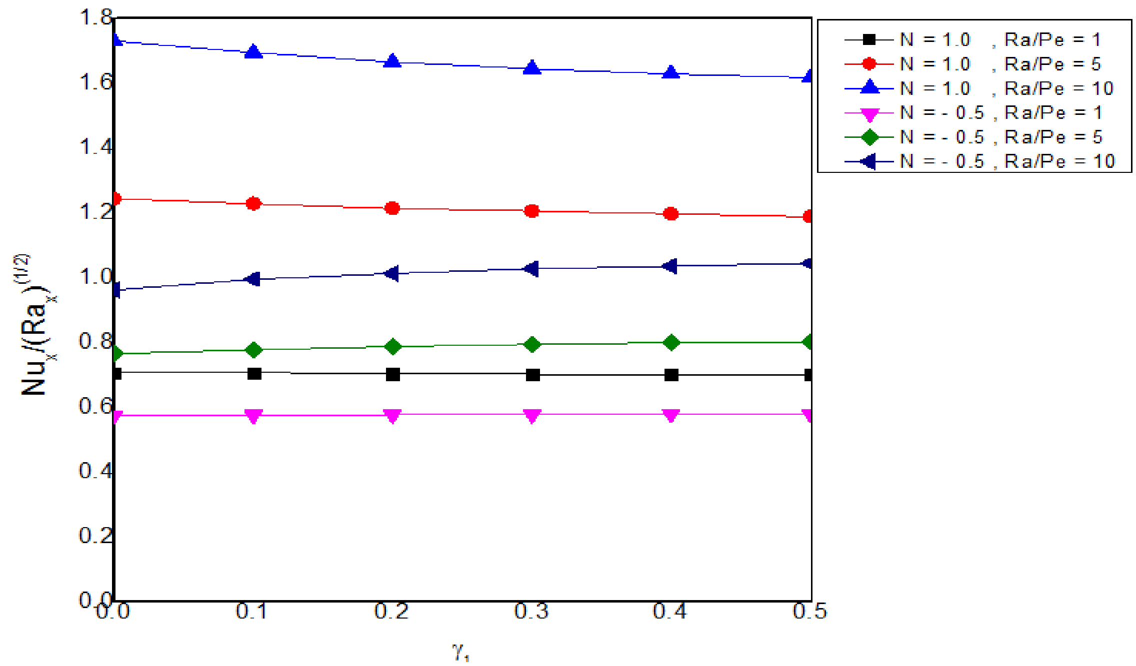

Fig. (12): Effects of chemical reaction on Nusselt number for different values of buoyancy ratio and mixed convection parameters $\left(F_0 Pe = 1, Le = 1, R = 1, S_r = 0.1, D_f = 0.6, Pe_\gamma = 1, Pe_\xi = 1\right)$

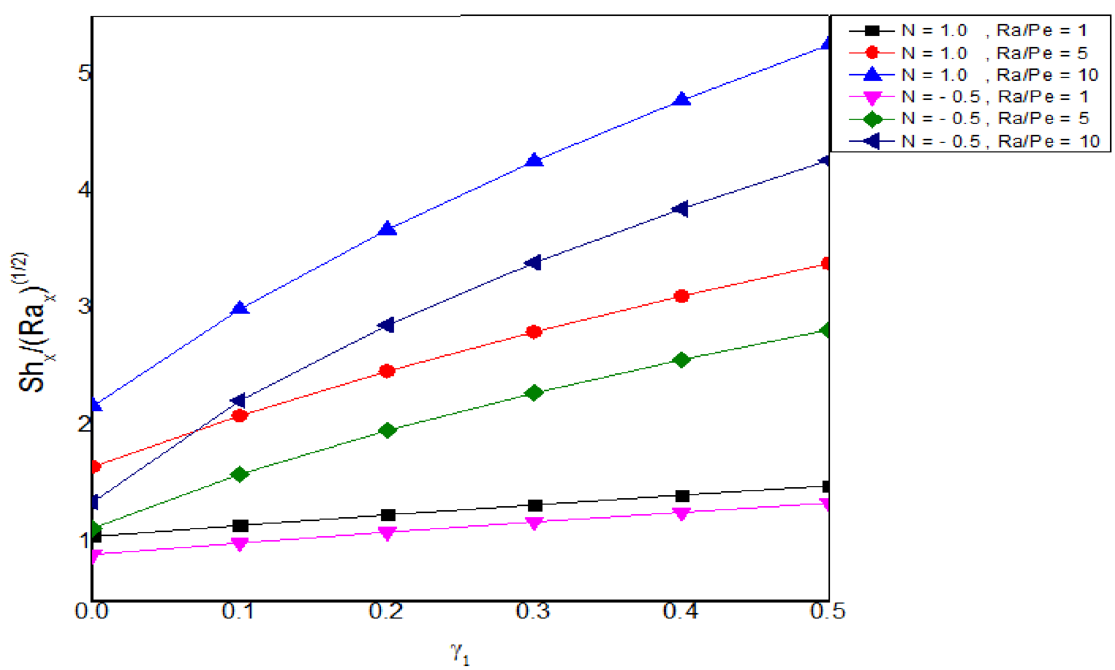

Fig. (13): Effect of Chemical reaction on Sherwood number for different values of buoyancy ratio and mixed convection parameter

$$\left(F_0 Pe = 1, Le = 1, R = 1, S_r = 0.1, D_f = 0.6, Pe_\gamma = 1, Pe_\xi = 1\right)$$

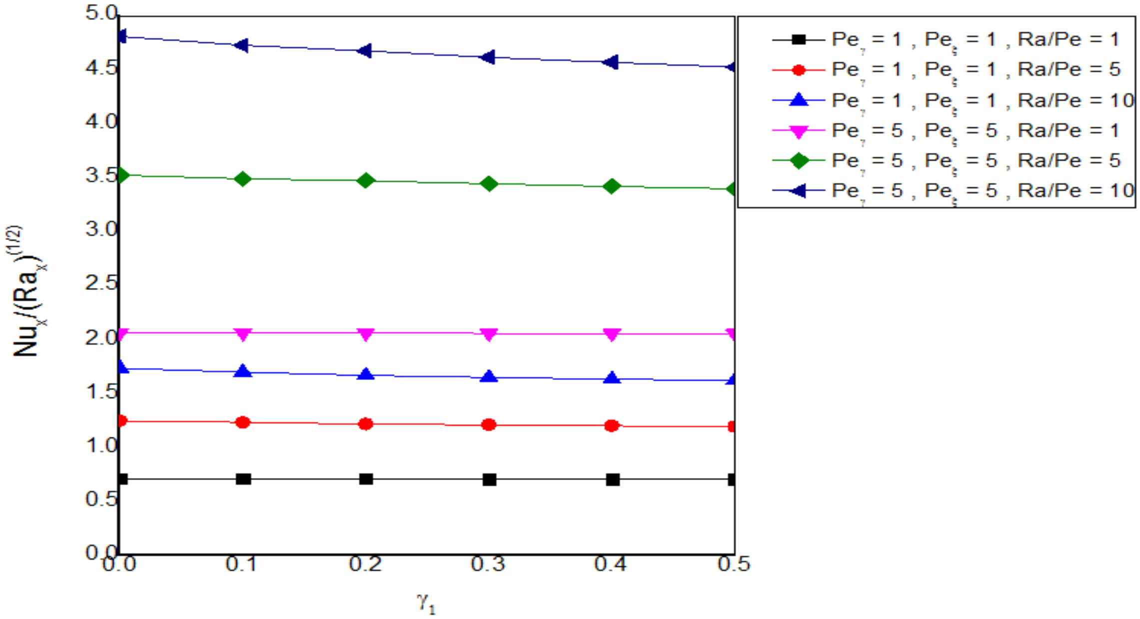

Fig. (14): Effect of Chemical reaction on Nusselt number for different values of dispersion and mixed convection $\left(F_0Pe = 1, N = 1, Le = 1, R = 1, S_r = 0.1, D_f = 0.6\right)$

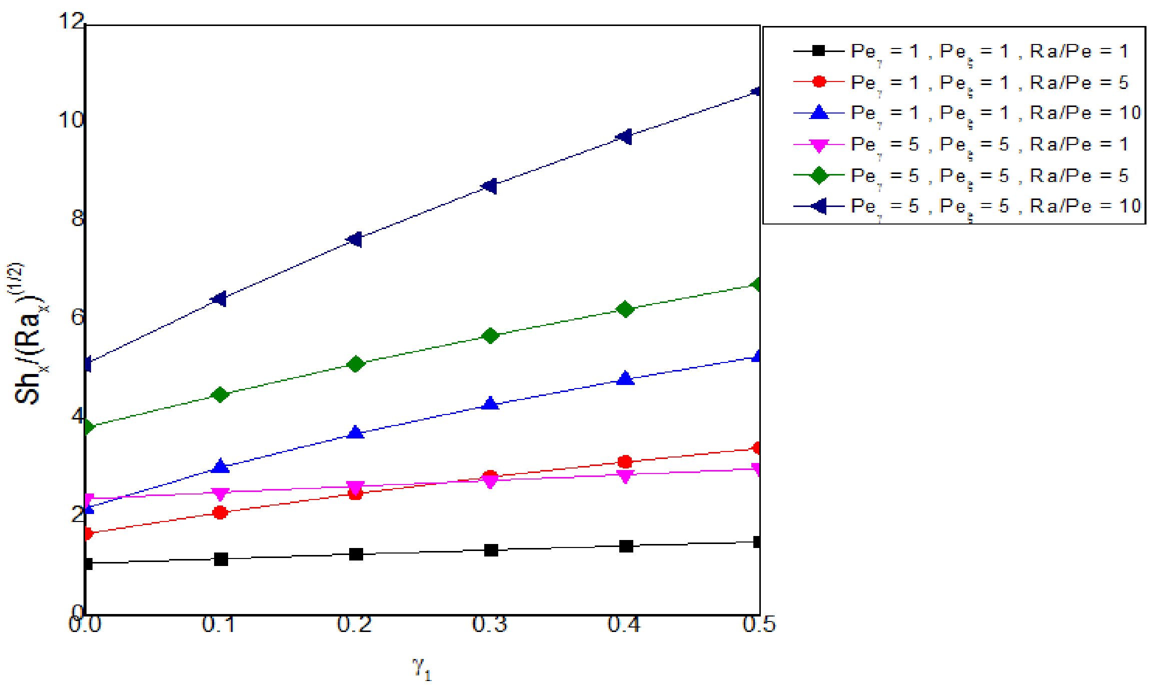

Fig. (15): Effect of Chemical reaction on Sherwood number for different values of dispersion and mixed convection parameter $\left(F_0Pe = 1, N = 1, Le = 1, R = 1, S_r = 0.1, D_f = 0.6\right)$

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